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THE EFFECTS OF FRAGMENT RICOCHET ON MUNITION LETHALITY

BOOZ, ALLEN & HAMILTON, INC.
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This report presents the results of a contractual effort to determine the effects of fragment ricochet on munition lethality in tactical environments and to develop modifications to the lethal area programs to account for fragment ricochet effects. The Degradation Effects Program (DEP) operational data was analyzed and used as the basis for the ricochet computer model. The ricochet model developed was incorporated into the computer program, Next Page

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EAGLE, which was previously designed to predict the lethal area of static DEP tests. The modified EAGLE computer program and its predictions for the BLU-3/B are presented in this report. These predictions show a correlation between experimental and predicted results.

SUMMARY

This report presents the results of a contractual effort to determine the effects of fragment ricochet on munition lethality in tactical environments and to develop modifications to the lethal area programs to account for fragment ricochet effects. The Degradation Effects Program (DEP) operational data was analyzed and used as the basis for the ricochet computer model. The ricochet model developed was incorporated into the computer program, EAGLE, which was previously designed to predict the lethal area of static DEP tests. The modified EAGLE computer program and its predictions for the BLU-3/B are presented in this report. These predictions show a correlation between experimental and predicted results.

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PREFACE

This report documents the results of a study to determine the effects of fragment ricochet on munition lethality. The study was performed during the period 10 January 1975 through 30 June 1975 by Booz, Allen, & Hamilton, Inc., P.O. Box 874, Shalimar, Florida, under Contract Number F08635-75-C-0055 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida. The program monitor for the Armament Laboratory was Mr. John A. Collins (DLYV).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

Roy C. Compton

ROY C. COMPTON
Acting Chief, Weapon Systems Analysis Division

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INTRODUCTION

The Joint Chiefs of Staff recognized the need for operational data based on munition performance rather than on theoretical data. The Degradation Effects Program (DEP) was set up to assess the influence of certain environments on the effectiveness of munitions and weapons. Although the main effort was to evaluate existing munitions, the objectives included developing the methodology and collecting data of a sufficiently general nature to aid in the evaluation of new items for future programs. DEP was essentially ended in 1972 due to funding limitations. Much of the methodology for predicting munition performance, particularly that dealing with fuze functioning, fragment ricochet, and fragment burial, was left in an incomplete state (Reference 1). The one area where major improvement could be made to the methodology within the constraints of limited resources is fragment ricochet effects.

The objective of this study was to determine the effects of fragment ricochet on munition lethality. The raw test data from the static arena tests conducted on the Air Force munitions were used as the basis for all analysis and modeling. The fragments penetrating the stationary targets were studied and the actual fragment encounters which were due to ricochet were identified. The effect of ricochet on lethal area was studied using the DEP experimental lethal area model. The DEP predictive lethal area model was modified to include the predictive capability of fragment ricochet effects on lethal area.

The frequency of occurrence of ricochet for the BLU-3/B munition in a number of operational environments is presented. The effect of ricochet on lethality computations and the significance of the effect are discussed.

SECTION II

DATA ANALYSIS

The raw data supplied by the Air Force Armament Laboratory at Eglin Air Force Base, Florida, was a portion of the massive amount of operational test data generated by the DEP program. The program encompassed the dynamic, static, and fuze testing of 34 key munitions in widely varied environments. Of these test situations, only the static tests for the Air Force munitions were subjected to analysis. The Air Force munitions test data were used to determine the frequency of occurrence of ricochet. All munitions were centered in a target array formed by standing 5- by 1- by 1-foot bundles in concentric rings (see Figure 1). The target bundles were arranged eight to a ring, with no target bundles providing shielding to others. The various tests were conducted with a large variation in the height of burst. This included testing some munitions partially buried. The weapon elevation angle was measured from the vertical axis with the weapon oriented nose down. Reference 2 provides a detailed description of individual weapon test arenas.

The fragment path was described by the entrance position on the front face of the bundle and the location of the fragment when the bundle was disassembled. In several cases, the fragment was lost, or it had penetrated the bundle and was noted as such. All measurements were made with respect to the forward, lower left-hand corner of the individual bundle. A right-handed coordinate system was used with the X-axis horizontal to the face of the bundle and the Y-axis vertical to the bundle.

The munition was described by the height of burst, elevation angle, and orientation. The radius of each of the target bundle rings, the tilt and orientation of the bundles, and the elevation of the individual target bundles was supplied to describe the test arenas in the various environments.

A typical form of data generated by static testing is shown in Figure 2 and is identified from left to right as: the munition shot number (8), the munition/environment identification (232C), the target ring, the target bundle spiral, the X-, Y-, and Z-coordinates of the entry point in inches, the X-, Y-, and Z-coordinates of the exit point in inches, and the fragment weight in grams.

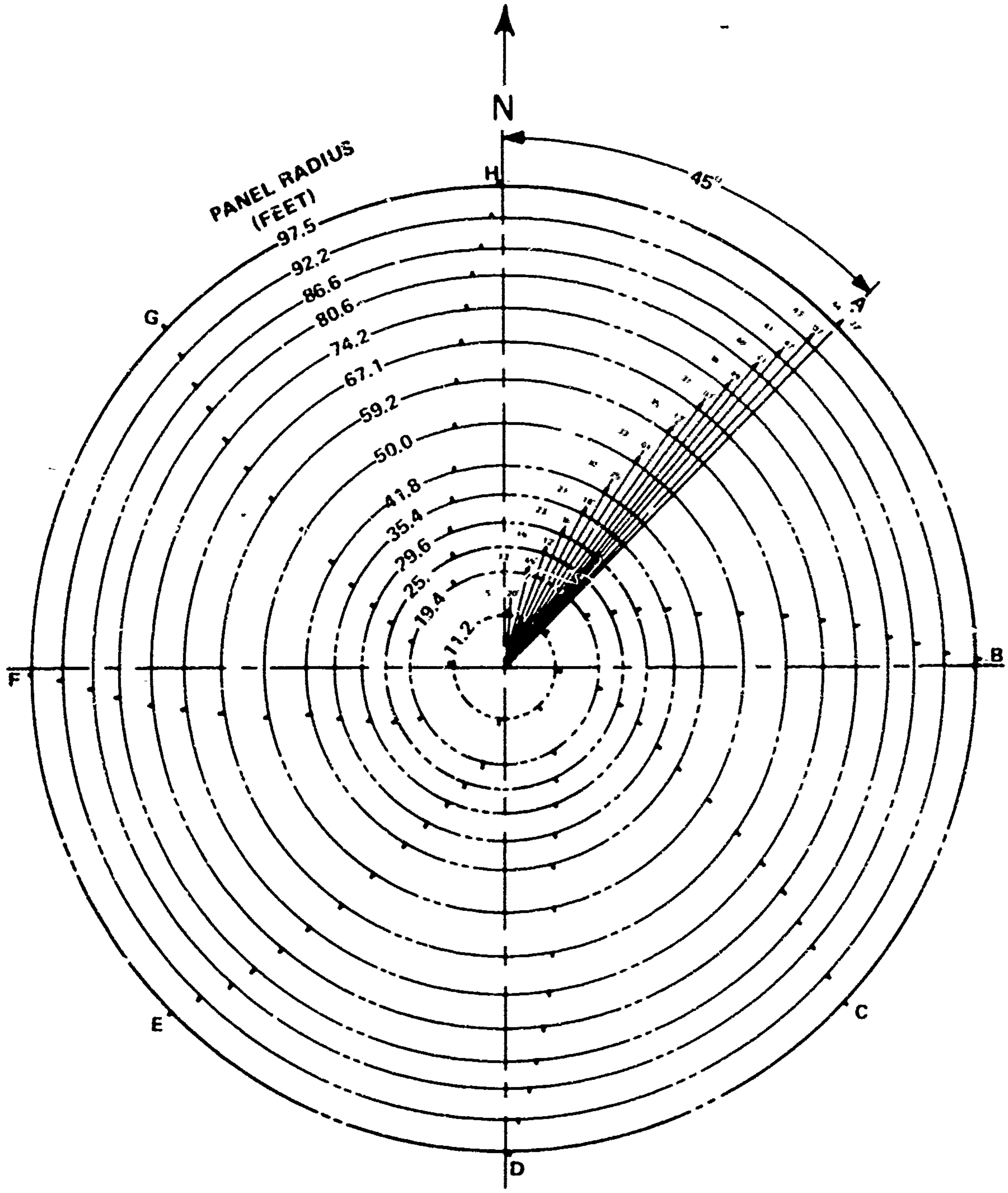

Figure 1. Target Array for Degradation Effects Program Static Tests

```
112  11                LINF  232  EGLIN TEST DATA  APPENDIX C  SHOT  8
       8     232C      1 A   8.0022.25 0.00 7.7523.00 7.00   1.016
       8     232C      1 A   2.2516.00 0.00 1.5016.5011.00   1.020
       8     232C      1 A   3.5029.50 0.00 2.5031.5011.00   1.021
       8     232C      3 A   5.7552.50 0.00 6.0052.50 3.00   1.022
       8     232C      1 B   6.5026.25 0.00 7.0027.75 6.50   1.016
       8     232C      1 E   7.7526.50 0.00 8.0027.00 2.50   1.015
       8     232C      1 F   5.2523.00 0.00 5.2525.00 9.50   1.019
       8     232C      1 E   3.5026.25 0.00 3.5030.5012.00   1.037
       8     232C      2 E   7.7526.50 0.0010.0028.50 9.50   1.018
       8     232C      5 F   4.5042.25 0.00 4.5043.50 8.50   1.010
       8     232C      5 E  10.0051.00 0.0010.2553.0012.00   1.018
       8     232C      6 E   3.5053.50 0.00 3.2554.50 5.50   1.015
       8     232C      1 F    .7529.50 0.00 1.7532.0011.00   1.018
       8     232C      8 F   1.0038.75 0.00 1.0038.75 6.50   1.012
       8     232C      1 G   4.7544.50 0.00 5.5043.50 8.50   1.037
       8     232C      7 H   5.5039.50 0.00 5.0040.50 8.50   1.020
```

Figure 2. Raw Data Form

A FORTRAN program was written to compute the apparent munition location for each fragment path and to select the fragments designated as ricochet by the various criteria. Data error was found to increase and sample size to decrease with respect to increasing distance from the munition detonation point. The measurement error was the same for every bundle, but the error in projecting the fragment path back to the munition location increased with distance. This circumstance led to the elimination of data from all but the four inner rings. The fragment path is traced back to its apparent origin using a straight-line formula. The omission of all outer ring data leaves the remaining data with sufficiently short trajectories that ballistic effect can be assumed to be negligible. The mean and standard deviations of the apparent fragment origin are calculated for each ring, and all points included within one standard deviation of the mean on the Y-axis are used to compute a second set of means and standard deviations. This procedure produced a more accurate estimate of the munition height.

The DEP fragment data format was designed for input to the lethal area programs and any other use of the data required special and tedious data handling procedures for operation. To enable the data to be used for various analytical procedures, it had to be transformed into a more flexible design.

The fragment information was stored in computer-based files. The computer-based storage and retrieval was conducted using the MARS VI (Multi-Access Retrieval System) data management system on the Control Data Corporation 6600 computer operated by the Armament Development and Test Center at Eglin

Air Force Base, Florida. The fragment data was organized to permit efficient data management, subsetting, sorting, and retrieval by considering the various data requirements. The pertinent fragment categories used to design the data base were:

- Fragment shot number.
- Target ring number.
- Target bundle identifier.
- Fragment entrance X-coordinate.
- Fragment entrance Y-coordinate.
- Fragment entrance Z-coordinate.
- Fragment terminal X-coordinate.
- Fragment terminal Y-coordinate.
- Fragment terminal Z-coordinate.
- Fragment mass.

The following paragraphs describe in detail the individual data analysis of the various munitions studied.

BLU-3/B

The BLU-3/B is a munition composed of preformed spherical fragments. Because of the homogeneity of the fragment shape and size and the relatively small range of inital fragment velocities (Reference 3), the BLU-3/B was selected for thorough analysis for ricochet effects. Table 1 is a summary of the arena and environment conditions for the individual tests; further detail is provided in Reference 2.

Initial testing of the BLU-3/B in open terrain indicated a higher fragment density reaching the target bundles than predicted by the Joint Munitions Effectiveness Manual (JMEM) weapons characteristics description. It was thought that this could possibly be the result of ricochet. A retest in the open terrain arena was performed. Five of the shots of the retest were conducted with the munition and target bundles raised 2 feet and ricochet stops installed (Reference 2) as shown in Figure 3.

TABLE 1. BLU-3/B TEST DESCRIPTION

Test Number	Terrain	Number of Shots	Height of Burst (Feet)	Munition Elevation Angle (Degrees)
225/B	High Canopy	5	0	30
		5	0	60
		5	15	30
		5	15	60
		5	25	30
		5	25	60
226/B	Dense Tangle	5	0	30
		5	0	60
		5	10	30
		5	10	60
227/B	Grass	5	1	30
		5	1	60
232/C[a]	Open, Eglin Sand	5	0	30
		5	0	65
232/C[b]	Open, Eglin Sand	5	0	30
		5	0	60
		5[c]	2	60
233/C	Temperate Forest	5	0	30
		5	0	65
		5	25	30
		5	25	65
		6	50	30
		6	50	65
235/C	Water	5	0	30
		5	0	60

[a] Original tests on Eglin sand.

[b] Retest on Eglin sand; double target bundles.

[c] Retest on Eglin sand; double target bundles; ricochet stops.

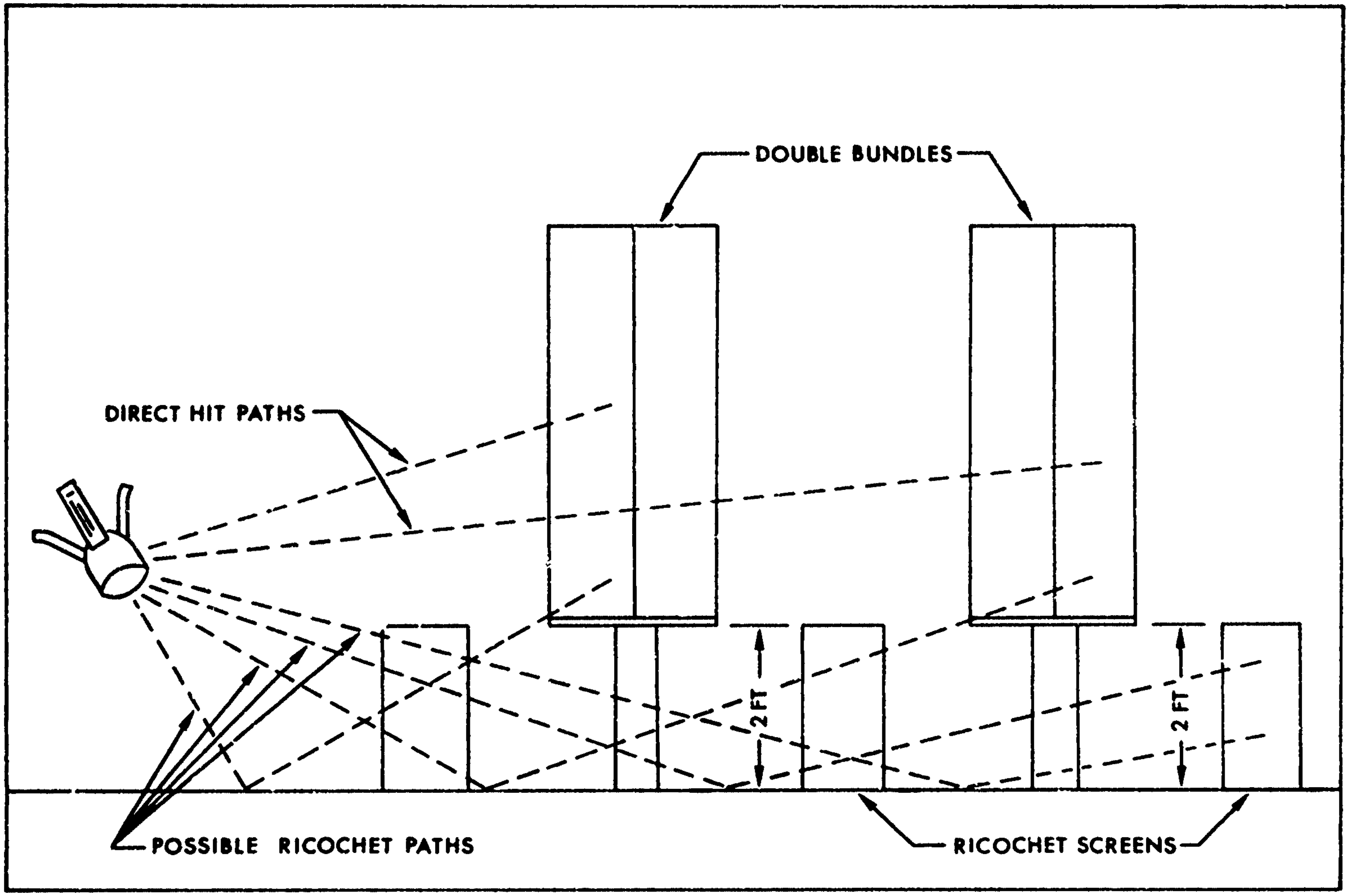

Figure 3. Elevated Target Bundles With Ricochet Screens for BLU-3/B Tests in Open Terrain

Three main criteria were used to assess the occurrence of ricochet. The first criterion used was depth of penetration. All fragments with a computed height of burst below the arena floor and a penetration of less than 7.5 inches into the target bundle were selected. This penetration depth corresponds to a minimum expected velocity of approximately 2,000 feet per second (Reference 4). The second criterion selected all fragments with a height of burst computed to be less than one standard deviation below the mean on the Y-axis. The third criterion compared the apparent angle of incidence (φ_i) and the angle of ricochet (φ_r) for each fragment. All fragments with an apparent ricochet angle less than or equal to the angle of incidence were picked as ricochet fragments. The point of impact on the arena floor was computed from the fragment entry and exit points on the target bundle. The height of the munition was assumed to be the mean plus one standard deviation. This defined height of burst compensates for 67 percent of the error in the fragment data, and thus makes the munition height a function of the error inherent in the data.

The results of the use of these criteria as ricochet selection models is summarized in Table 2 for three of the test environments. All of the above criteria were consolidated for the fourth ricochet criterion. The results shown in Table 2 indicate a negligible enhancement due to ricochet. The fifth consideration combined the first and third ricochet criteria. This ricochet model has the advantage, unlike the previous method, of not omitting a common form of ricochet, a fragment ricocheting with a very low angle into the target bundle. The results show an increased enhancement from ricochet in most cases.

The origination points for the individual fragment paths were plotted in the X-Y plane at Z = 0, the munition detonation point. With the weapon detonating on the ground, the error in calibrating the fragment path at the target bundles resulted in the location of a significant number of fragment origination points below the ground. This is further evidence that there could exist some low angle ricochet which is unaccounted for when using the second ricochet model. Ricochet test results over Eglin sand arenas (summarized in Reference 5) show that fragments have a 50-percent probability of ricocheting when the angle of incidence is less than 17 degrees.

The third ricochet model defined an overly large number of fragments as ricocheting fragments. It was decided that there were too many unknown factors concerning the arena surface to always rely on the ricochet angle criteria.

TABLE 2. SUMMARY OF RICOCHET SELECTION CRITERIA

Test Environment	Sample Size	Criterion 1: Z < 7.5; Y_0 < 0.0	Percent Enhancement	Criterion 2: $Y_0 < \bar{Y} - \sigma$	Percent Enhancement	Criterion 3: [illegible]	Percent Enhancement	Criterion 4: Criteria 1,2, and 3	Percent Enhancement	Criterion 5: Criteria 1 and 3	Percent Enhancement	Hits Predicted From Weapon Description
Grass												
Ring 1	58	4	5	9	11	2	2	2	2	2	2	74
Ring 2	36	2	6	3	9	2	6	1	3	1	3	47
Ring 3	31	5	19	3	11	4	15	0	0	1	3	37
Ring 4	42	0	0	3	33	1	9	0	0	0	0	11
Cumulative	167	11	7	18	12	9	6	3	[illegible]	4	2	169
Open[a]												
Ring 1	98	12	14	6	7	42	75	1	1	11	13	74
Ring 2	48	14	41	7	17	23	92	0	0	8	20	47
Ring 3	21	5	31	6	40	6	49	1	17	3	17	35
Ring 4	15	3	25	5	50	1	7	0	0	0	0	12
Cumulative	182	34	23	24	15	72	65	4	2	22	14	168
Open[b]												
Ring 1	101	14	16	5	5	59	140	0	0	13	15	122
Ring 2	49	7	17	6	14	0	0	0	0	0	0	75
Ring 3	20	4	25	3	18	8	67	1	5	2	11	55
Ring 4	11	2	22	2	22	2	22	0	0	1	10	20
Cumulative	182	28	18	17	10	69	61	1	1	16	10	272
Open[c]												
Ring 1	101	14	16	5	5	65	180	0	0	13	15	122
Ring 2	49	7	17	6	14	2	4	0	0	0	0	75
Ring 3	20	4	25	3	18	9	82	1	5	2	11	55
Ring 4	11	2	22	2	22	3	37	0	0	1	10	20
Cumulative	182	28	18	17	10	79	77	1	1	16	10	272
Water												
Ring 1	67	7	12	7	12	16	31	4	6	6	10	74
Ring 2	31	7	29	3	11	13	72	1	3	6	24	47
Ring 3	21	2	11	5	31	4	24	2	11	2	11	35
Ring 4	21	1	5	1	5	2	11	0	0	0	0	12
Cumulative	140	16	13	16	13	35	33	7	5	14	11	168

[a]Original test work.

[b]Retest data without bundle height corrections.

[c]Retest data with bundle height corrections.

One additional method of screening for lethality enhancement due to ricochet is to compare test results with the predicted number of hits given in a weapon characteristics description of the munition. Although this information is applicable to an open terrain environment, it can serve as a gauge of the number of expected nonricocheting hits in other environments.

The purpose of the above analysis was to determine which form of ricochet model would be suitable for use with the DEP study data. The results, as presented in Table 2, indicated that the depth of penetration model would be the most applicable.

One area of concern was the omission of individual target bundle elevations on some test data. To determine whether target bundle height could be ignored in our test analysis, the open terrain retest study was analyzed both with and without the elevation heights included. The results of this comparison are included in Table 2. In most cases, the same number of ricocheting fragments were predicted whether or not the target elevation data were included. The plots of the inner target rings of both yielded almost identical graphs. It was concluded that for relatively flat test arenas the omission of the individual target elevations would not significantly affect analysis when the inner ring fragment data were used.

Ricochet tests conducted by Cornell Aeronautical Laboratory (Reference 6) were referred to in order to determine possible ricochet behavior. Test results indicate that fragment velocity reduction due to ricochet is not as large as that assumed by this study's initial analysis, as presented in Table 2. Therefore, the cut-off depth of penetration criterion was raised to 9.0 inches. This value roughly corresponds to a velocity of 2,400 feet per second (Reference 4). Compared to the top speeds that BLU-3/B fragments are capable of attaining, this can be considered a conservative estimate. The revised model was exercised using the open terrain retest data. The results of this analysis were separated according to the different test conditions. A summary of the results is given in Table 3. Shot numbers 1 through 5 were with the arena set up with the munition elevated at a 30-degree angle. The munition was elevated at a 60-degree angle for shot numbers 6 through 10. Shot numbers 11 through 15 had ricochet fences installed, and the munition had an elevation angle of 60 degrees.

One of the major differences observed was the marked reduction in fragments collected for the test setup with ricochet

TABLE 3. SUMMARY OF RICOCHET PREDICTIVE METHOD RETEST WORK IN OPEN TERRAIN

Fragment Evaluation	Shot Numbers 1 - 5[a]				Shot Numbers 6 - 10[b]				Shot Numbers 11 - 15[c]			
	Rings 1	Rings 2	Rings 3	Cumulative	Rings 1	Rings 2	Rings 3	Cumulative	Rings 1	Rings 2	Rings 3	Cumulative
JMEM Weapon Description[d]	25	20	15	60	47	27	22	96	47	27	22	96
Number of Hits[e]	33	20	8	61	39	17	8	64	29	13	4	46
Ricochet Number[d]; $Y_0 < 0$, $D^f < 9$	7	6	2	15	8	6	4	18	7	3	[g]	10
Percent Enhancement	27	43	33	33	26	55	100	39	32	30	[g]	31
Number of Hits; Lost Fragments Omitted[e]	31	19	8	58	31	16	8	55	22	11	2	35
Ricochet Number[d]; Lost Fragments Omitted; $Y_0 < 0$, $D^f < 9$	7	5	2	14	7	5	4	16	1	2	[g]	3
Percent Enhancement	29	36	33	32	29	45	100	41	5	22	[g]	10

[a] Elevation angle of 30 degrees.

[b] Elevation angle of 60 degrees.

[c] Elevation angle of 60 degrees; ricochet fences installed.

[d] Predicted number.

[e] Actual number.

[f] Depth of penetration into target bundle.

[g] Sample size too small.

fences as compared to similar tests without ricochet fences. The total fragment count went from 64 fragments collected without ricochet fences to 46 with ricochet fences—a decrease of 28 percent. It was thought that this reduction in fragments was due to the omission of all ricocheting fragments by employing the ricochet fences in the testing environment. However, when the ricochet criteria was applied to the retest data, the results in Table 3 indicated a significant frequency of ricochet occurrence with ricochet fences installed. A detailed investigation indicated that the ricocheting fragments selected were fragments that had actually been lost or whose paths had directed them close to the edge of the bundle, where trajectory curvature within the bundle material becomes predominate. The ricochet model was then applied to the retest data with all fragments that had been lost or that had penetrated the target bundles omitted from the fragment data. The results of this analysis showed a major reduction in ricochet predicted for the shots incorporating the ricochet stops, a decline from 41 percent to 10 percent enhancement due to ricochet, while the other test shots showed only minor differences. This information substantiated two assumptions. It provided proof that the reduction in fragment hits for the test incorporating the ricochet fences was due to the omission of ground ricocheting fragments. The inclusion of the lost fragment data was shown not to noticeably affect the standard test results. In addition, it verified the conservative nature of the ground ricochet predictions.

The ricochet selection criterion used for all further BLU-3/B test analysis was a depth of penetration of less than 9 inches and a computed origination point below ground level. The ricochet model was applied to all BLU-3/B test data. Table 4 is a comparison of the predicted ricochet effect for the BLU-3/B in various environments. Because individual target bundle heights were not supplied with the original data for test numbers 226, 227, and 233, the target elevation data were omitted from all analysis. Since these arenas were relatively flat, this omission did not affect the analysis, as suggested earlier.

Results indicate that ricochet effects are the most significant in a ground burst situation. The only exceptions observed were for the temperate forest tests. For burst heights above ground level, these tests produced very few fragments, which would explain their unpredictable results. The difference in enhanced fragment density due to ricochet in the various environments is primarily a function of the material and condition of the arena floor.

TABLE 4. COMPARISON OF BLU-3/B RICOCHET EFFECTS IN VARIOUS ENVIRONMENTS

Environment	Height of Burst (Feet)	Number of Fragments in Ring: Total Number, Ring 1	Total Number, Ring 2	Total Number, Ring 3	Total Number, Cumulative	Number of Ricochet, Ring 1	Number of Ricochet, Ring 2	Number of Ricochet, Ring 3	Number of Ricochet, Cumulative
High Canopy	25	10	4	4	18	0	0	0	0
Percent Enhancement						0	0	0	0
High Canopy	15	12	8	8	28	2	0	1	3
Percent Enhancement						20	0	14	12
High Canopy	0	69	28	7	124	21	4	2	27
Percent Enhancement						31	17	40	28
Dense Tangle	10	37	15	12	64	2	2	0	4
Percent Enhancement						6	15	0	7
Dense Tangle	0	71	21	16	108	9	4	6	19
Percent Enhancement						15	24	30	21
Grass	1	88	36	31	155	4	2	5	11
Percent Enhancement						5	6	19	8
Open[a]	0	98	48	21	167	19	15	6	40
Percent Enhancement						24	45	40	31
Open[b]	0	72	36	16	124	15	11	6	32
Percent Enhancement						26	44	60	35
Open[c]	0	29	13	4	46	7	3	1	11
Percent Enhancement						32	30	25	31
Temperate Forest	50	1	1	3	5	0	1	1	2
Percent Enhancement						0	100	25	67
Temperate Forest	25	6	8	3	17	0	2	1	3
Percent Enhancement						0	33	50	21
Temperate Forest	0	49	21	10	80	5	3	1	9
Percent Enhancement						11	17	11	13
Water	0	67	31	21	119	9	11	2	22
Percent Enhancement						16	55	11	23

[a] Original open tests.

[b] Retest work in open arena.

[c] Retest work with ricochet stops.

The computer program FOREST-III, developed at Picatinny Arsenal, was used to evaluate the DEP project static test results in terms of lethal area. The original lethal area computations for the BLU-3/B and other Air Force munitions are given in Reference 7. FOREST-III was again used to compute the lethal area for the BLU-3/B munition with the input data modified. Three runs were made for each test environment.

- A run was made with all data intact like the original analyses.

- A run was made using direct hitting fragment data only—ricocheting fragments (as previously defined) were omitted.

- A run was made using ricochet hits only. The equation for computing striking velocity (V_S) from depth of penetration was changed as documented in Reference 4. Equations (9) and (14) of Reference 4 defined for spheres were:

$$V_S = \alpha\sqrt{\frac{e^{[321300\ D(A_p)/M]} - 1}{4.25}}$$

where α is a function of fragment size, D is the depth of penetration in inches, A_p is the fragment's presented area in square feet, and M is the mass in milligrams.

Table 5 is a summary of the lethal area evaluations defined in this manner. In the cases where the munition detonation position was far off of the ground, the fragment sample size was small and, consequently, any calculations with this data had a high degree of uncertainty. Results of the lethal area evaluations showed that, with ricochet effects included, the average enhancement in lethal area was 25 percent. The variation is due to the different elevation angles of the munition, the height of burst, and the different environmental conditions. The most significant results, as indicated in Table 5, show that ricochet is most predominant at low heights of burst and can be expected to occur most frequently in an open sand environment.

TABLE 5. ENVIRONMENTAL LETHALITY COMPARISONS

Environment	Height of Burst (Feet)	Elevation Angle (Degrees)	Number of Shots	Average Lethal Area: Total Hits	Average Lethal Area: Nonricochet Hits Only	Percent Enhancement
High Canopy	25	30	5	303	260	17
	25	60	5	246	182	35
	15	30	5	716	626	14
	15	60	5	444	426	4
	0	30	5	599	434	38
	0	60	5	858	749	15
Dense Tangle	10	30	5	757	723	5
	10	60	5	598	513	17
	0	30	5	1,022	745	37
	0	60	5	978	764	28
Grass	1	30	5	853	770	11
	1	60	5	1,465	1,410	4
Open[a]	0	30	5	1,081	950	14
	0	65	5	1,768	1,439	23
Open[b]	0	30	5	844	474	78
	0	60	5	1,343	847	59
	0	60	5[c]	750	618	21
Temperate Forest	50	30	6	51	51	0
	50	65	6	205	137	50
	25	30	5	362	320	13

[a] Original tests.

[b] Retest.

[c] Retest; ricochet stops.

TABLE 5. (CONCLUDED)

Environment	Height of Burst (Feet)	Elevation Angle (Degrees)	Number of Shots	Average Lethal Area: Total Hits	Average Lethal Area: Nonricochet Hits Only	Percent Enhancement
	25	65	5	592	474	25
	0	30	5	478	439	9
	0	65	5	919	810	13
Water	0	30	5	1,093	986	11
	0	60	5	1,626	1,267	28

[a] Original tests.

[b] Retest.

[c] Retest; ricochet stops.

BLU-26/B

The BLU-26/B is similar to the BLU-3/B in that it is a munition composed of preformed spherical fragments. However, the JMEM weapon characterization of it does not predict the homogeneity of the fragment size like it did for the BLU-3/B. This may be due to fragment break-up and would therefore be a function of environment. Consequently, a slightly larger range of fragment velocities is predicted by the JMEM.

The major disadvantage in the analysis of the BLU-26/B was the lack of testing incorporating this munition. The BLU-26/B was only tested in Type I snow (Reference 2). The height of burst used in the snow testing varied from surface level to complete burial of the munition in snow. The fragments emitted from the buried munitions could not contribute to ricochet and only distorted the height of burst location because of their tendency to follow nonlinear paths in the snow. It was for these reasons that this munition was not considered for ricochet analysis.

MK82 BOMB

The MK82, a 500-pound bomb, was tested in the high canopy, dense tangle, open, temperate forest, and water environments. The MK82 exhibited a wide range in fragment size, shape, and velocity. In addition, the bomb destroyed some of the inner ring target bundles. Consequently, in many cases the most informative data on the MK82 fragment behavior was destroyed. This munition was not used for ricochet analysis.

2.75-INCH ROCKET

The 2.75-inch rocket was tested in the high canopy, dense tangle, grass, open, temperate forest, mud, and water arenas with the M151 warhead, and in the high canopy, dense tangle, grass, open, and temperate forest environments with the MK-5 warhead. Both warheads produced a very large variation in fragment size and velocity. In all cases, the frequency distribution of fragment weights and penetration capabilities was biased toward the smaller fragments. Differentiation among the direct fragments, broken-up fragments, and miscellaneous debris in the large percentage of very small fragments was the major difficulty. In addition, the fragment shape was unknown. Because of the variability and deficiency of information, ricochet analysis on the 2.75-inch rocket was not considered.

SECTION III

PROPOSED CHANGES TO COMPUTER MODEL

Munition lethality computations are generally performed using the JMEM weapon characteristics data. These weapon characterizations are primarily based upon static fragmentation tests conducted in a test arena designed to produce a rayline description of the fragment behavior without regard to any outside interference. It was illustrated in the previous section that fragment ricochet contributes to a munition's lethality to various extents. It would be advantageous to be able to simulate fragment ricochet behavior in computer lethality programs.

Fragment ricochet models describe in more detail the actual events that take place when a munition detonates in a real environment. Lethality computations from these models give a more precise indication of the capability of various munitions in differing environments. To date, the Air Force lethality computer programs do not have a ricochet model incorporated into them. This is due to the complexity of the ricochet parameters and the lack of knowledge of their relations in differing environments.

The predictive lethal area computer program (EAGLE) for statically detonated munitions in a DEP style arena was developed by the Computer Programs and Evaluation Models (CPEM) Subgroup of the DEP Methodology and Evaluation Working Group (MEWG) (References 8 and 9). The EAGLE program assumes a point fragment source at the center of the arena. The fragment density emanating from the point source and impinging upon a defined target is computed from the conical polar zones describing the fragment distribution coming out from the point source (an input to the program) and the distance of the target from the point source. The target bundles, situated in a spiral fashion circumventing the point source, are described as a six-point man and as a one-point man. The fragment density directly striking the target bundles is defined at each of the target points or at the single point. The density at the point is assumed to be applicable for the entire area around the point.

The test arena environment is divided into layers which describe the biomass density affecting fragment velocity. In addition, contributions to the biomass density by trees and large branches are considered to account for target shielding.

EAGLE limits its munition simulation to directly hitting fragments only. This computer model does not take into consideration the effects of round-to-round variations on munition capability and fragment ricochet.

In developing the ricochet model, it was decided that the most convenient method for testing the effects of the ricochet model was to incorporate it into the EAGLE program. Since EAGLE had been designed to compute the predicted lethality of a munition, insertion of a ricochet model would provide direct comparison with published results (Reference 10) and would compensate for fragment ricochet in the munition lethality simulation.

There are two major methods for developing a simulation model. One method develops from the treatment of laboratory testing data, which isolates each individual phenomenon contributing to the results. The second method makes use of empirical data, allowing it to inherently express all variables without regard to what these variables actually may be. Because of the availability of the data from the DEP program and the ricochet analysis applied to it by this study, the second method was chosen.

When ricochet takes place, there are several occurrences that have a major effect upon the fragment path. The fragment's encounter with the ground is likely to cause fragment burial or possibly fragment break-up. Upon ricocheting from the ground, the fragment has a new velocity, angle of incidence on a target, and weight. The DEP raw data was analyzed with respect to these three parameters to develop a relationship for each under each test setup.

Since the initial DEP ricochet analysis was performed primarily on the BLU-3/B, the BLU-3/B data was selected as the basis for the ricochet model. Only on rare occasions was the BLU-3/B observed to break up. Thus, the assumption was made that the fragment weight remained constant throughout any ricochet occurrence. This assumption reduces the ricochet parameters and simplifies the ricochet model considerably.

The results from the application of the ricochet criteria, as defined in the previous section, were used to determine the degree to which ricochet reduced the fragment velocity in each environment. A critical ricochet angle was defined as the angle at which 50 percent of all ground hits would produce ricochet.

Analysis of the DEP data led to the development of a basic, heuristic ricochet model. Insertion of this model into the EAGLE computer program did not degrade the logic and computational capability already available in EAGLE. To insure compatibility, the ricochet assumptions are similar to the assumptions in the EAGLE computer program. The assumptions implied in the ricochet model are:

- Fragment weight and shape remain unchanged during ricochet.

- The fragment density impinging upon the center of the ground ricochet area directly in front of each target bundle applies to the entire ground ricochet area for that bundle.

- The probability of the fragments ricocheting from the critical ricochet zone out of the bundle pathline approximates the probability of the fragments ricocheting from outside the critical ricochet zone into the bundle pathline.

- The ricocheting fragment travels through an environment similar to the environment experienced by a fragment directly hitting the lowest point on the target bundle.

- The ricochet angle approximates the ground incidence angle.

Figures 4 and 5 are the flow diagrams of the logic of the ricochet model as it was incorporated into the EAGLE computer program. The critical ground ricochet area directly in front of each target bundle was computed. This area is bounded by the line drawn between the munition and each side of the bundles on two sides and by the critical ricochet angle and the base of the target bundle on the other two sides.

A representative fragment ricochet path is selected by taking the average of the critical ricochet angle and the angle from the munition to the base of the target. The presented area of the critical ground ricochet area is then computed in the plane normal to the representative fragment ricochet path.

The ricochet presented area is further reduced for those cases where the fragment may ricochet over the top of the target bundle. The largest ricochet angle is assumed to be equal to the critical ricochet angle. This angle is projected onto

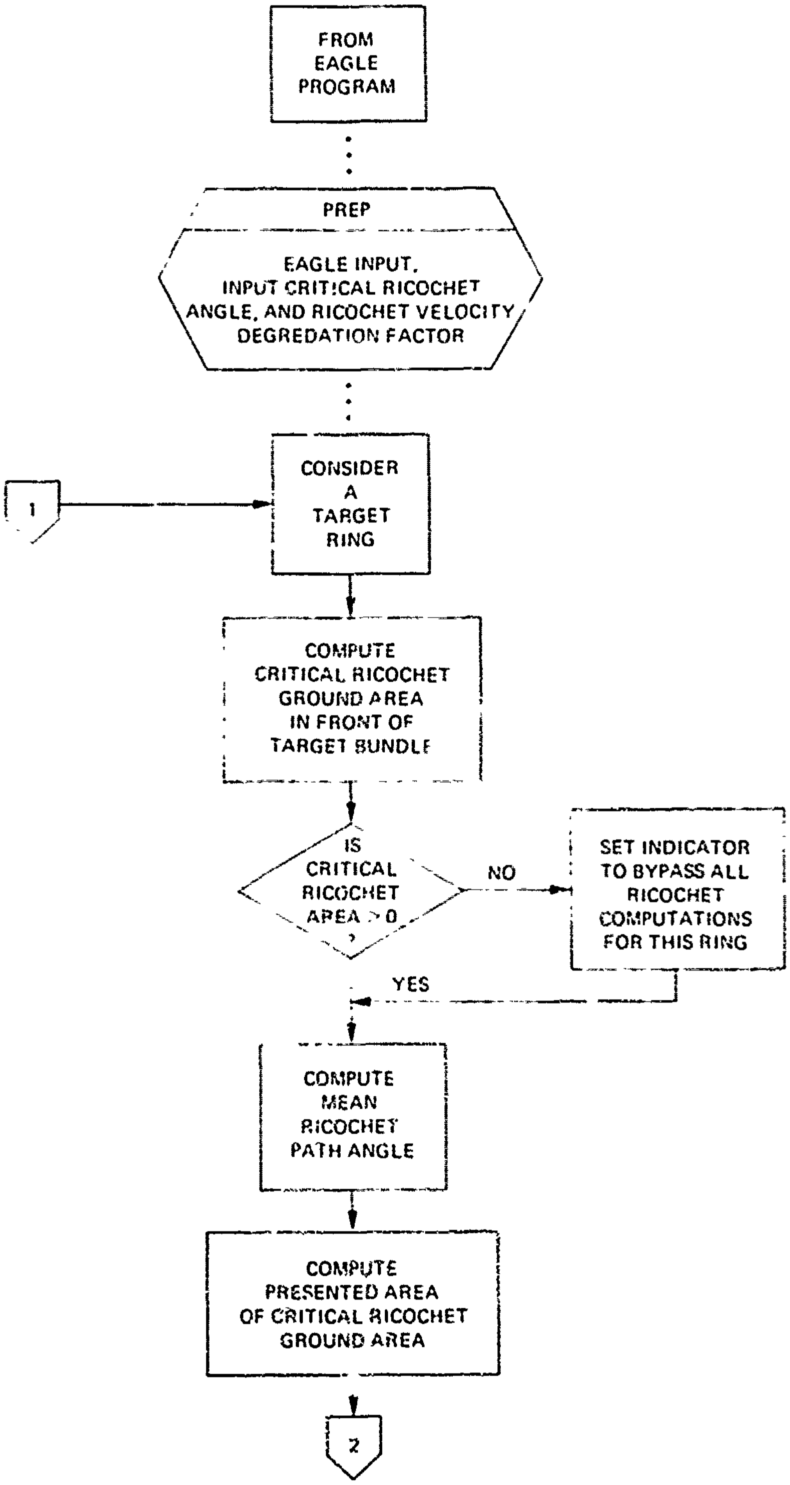

Figure 4. Flow Diagram of the Ricochet Model in EAGLE's Main Program

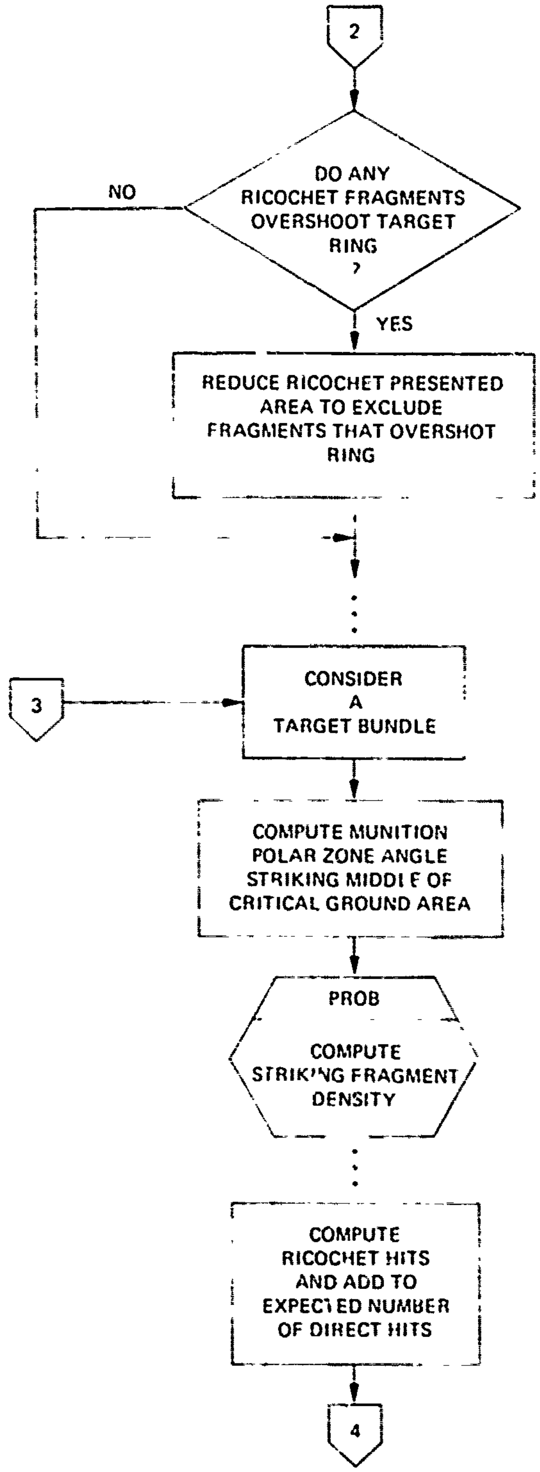

Figure 4. (Continued)

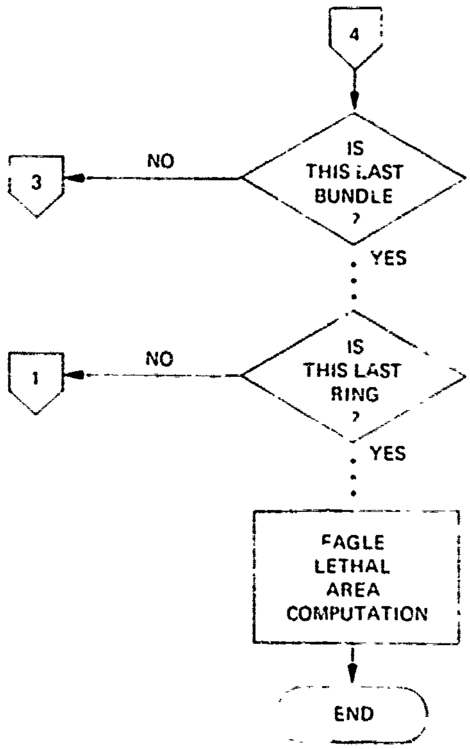

Figure 4. (Concluded)

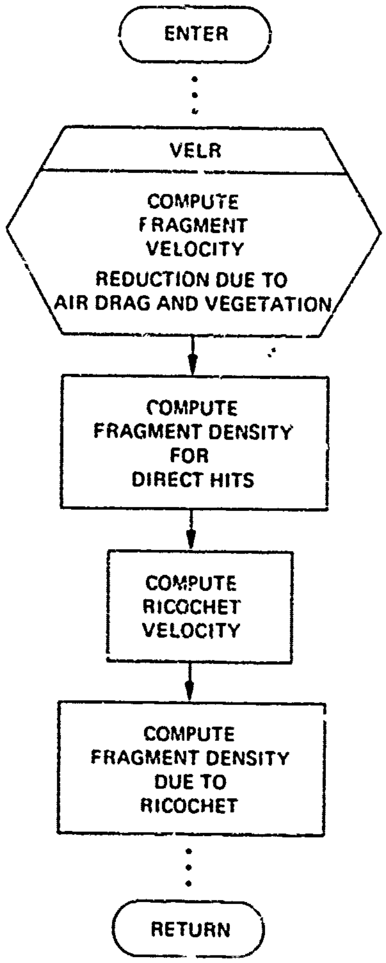

Figure 5. Flow Diagram of Subroutine PROB

the target bundles in each ring. For those instances where the fragment projection overshoots the target, the ricochet presented area is reduced until the reflection of the angle to the edge of the ricochet zone meets the top of the target.

The munition polar zone angle representative of the average ricochet path is computed as the arc cosine of the cross product of two vectors. The first vector is the extension of the munition axis to the arena floor. The second vector is the path of the fragment from the munition to the middle of the ricochet zone in front of each target bundle. The resulting angle is compared with the weapon description fragment distribution to determine the polar zone responsible for contributing to ricochet for that particular target bundle.

The velocity degradation routines already available in the EAGLE computer program are used for the ricochet velocity degradation computation. The subprogram designed to compute the striking fragment density is entered for every point on the six-point man target. At the time the fragment density is computed for the lowest point on the target, the ricochet density is computed. The velocity for the direct hitting fragments is obtained after they have undergone all velocity reduction operations. For ricochet fragments, this value is then multiplied by the velocity degradation factor to account for the velocity loss due to striking the ground and possible furrowing. The ricochet fragment density is computed in a manner similar to the computation of the direct fragment density (Reference 9) using the ricochet velocity, the selected ricochet polar zone fragment number, and the solid angle produced by the ricochet polar zone.

The number of ricochet hits for a particular target bundle is computed by multiplying the ricochet presented area times the ricochet fragment density. This value is added to the expected number of direct hits to obtain a total expected number of hits. EAGLE continues with its computation of lethal area given the total expected number of hits.

OTHER RICOCHET MODELS

The Army Materiel Systems Analysis Agency (AMSAA) designed a ricochet model for use in the lethality computer program at AMSAA (Reference 5). Unlike the ricochet model presented in this report, which was based on the DEP operational data, the AMSAA model was based upon laboratory test data designed to explore specific aspects of fragment

ricochet. In addition, the AMSAA target representation has no relation to the DEP style arenas referred to in this report.

Towards the end of the project, it was discovered that the ricochet model had been incorporated into the EAGLE computer program by Picatinny Arsenal, Dover, New Jersey. A comparison of the two models has not been made.

RESULTS

Two computer models were used to determine the effectiveness of the ricochet model design. These were the DEP predictive computer program EAGLE, and EAGLE modified to incorporate the ricochet model as outlined above.

The input to these two computer models was prepared to approximate the conditions in the actual test environments. The munition elevation angle and height of burst were varied in an attempt to verify the placement of the munition in the various test environments. The only environments evaluated were high canopy, dense tangle, and open test arenas since the EAGLE input data to other test environments were not available. The input information to the two computer programs was similar to that used in the original analysis (Reference 10); however, the intent was not to reproduce the lethality figures in Reference 10.

Table 6 is a summary of the results produced from these two computer models. The minimum and maximum lethal areas computed were a function of munition elevation angle and height of burst. The nonricochet results indicate that in all environments the highest lethality effects are predicted for ground level detonations. At low munition altitudes, munitions with a 60-degree elevation angle were the most lethal and, at high altitudes, the 30-degree elevation angle is the predominately lethal one, as shown with the high canopy data. The addition of the ricochet model did not affect these relationships. The ricochet model produced greater lethal area enhancement for the munition oriented at an angle of 30 degrees.

The sandy surface of the open test arena seemed to provide a better ricochet medium than the earthen surface of the high canopy and dense tangle environments. The relationship between the cohesive nature of soils and the critical ricochet angle, as detailed in Reference 5, was the source of the critical ricochet angle selection. Ricochet was permitted

TABLE 6. COMPARISON OF BLU-3/B LETHAL AREA PREDICTIONS

Test Environment	Height of Burst (Feet)	Munition Elevation Angle (Degrees)	Predicted Lethal Area						Percent Enhancement
			Nonricochet Model			Ricochet Model			
			Minimum	Maximum	Average	Minimum	Maximum	Average	
High Canopy	25	30	390	608	501	390	612	502	0
	25	60	224	438	346	224	443	349	1
	15	30	605	738	671	664	803	730	9
	15	60	499	683	608	600	836	718	18
	0	30	644	831	736	792	1002	894	21
	0	60	954	1525	1229	1134	1797	1453	18
Dense Tangle	10	30	703	946	821	814	1080	933	14
	10	60	935	1088	1010	1068	1305	1174	16
	0	30	620	792	708	740	932	837	18
	0	60	919	1459	1177	1067	1676	1359	15
Open	0	30	717	918	815	895	1113	994	22
	0	60	1065	1711	1356	1277	2011	1609	19

below an incidence angle of 17 degrees in the open terrain and below an incidence angle of 14 degrees in the high canopy and dense tangle. The actual composition of the soil in the latter two environments was not known. This fact had little effect on the results since there is little difference between the various ricochet angles. An analysis of the penetration characteristics indicated that the fragments selected as ricochet hits in the open environment had higher velocity measurements than did the ricochet hits in either of the other two environments tested. This information was used to describe the effects of the different soils on ricochet. In fact, the velocity vectors of the high canopy and dense tangle were similar, indicating similarity in soil content.

The predictive lethal area results of Table 6 were compared with the computed lethality in Table 5. The predicted results indicate higher values than expected from the computed lethalities in the environments where there was dense vegetation. Consequently, an addition to lethality from ricochet only compounds the problem. This cannot be considered as an accurate gauge of the ricochet model's credibility. The problem for these environments must lie in the original data or in EAGLE's representation of these environments. Reference 10 documents several of the suspected problem areas. In particular, the inability to properly represent the vegetative environment and its effect on fragment trajectories could have strongly affected the lethality results.

Comparison of the predictive lethalities in open ter in with the computed lethalities of the retest work in open terrain indicates a closer agreement with the EAGLE computer program without the ricochet model. However, the data that was obtained from a test arena with ricochet fences, a test condition that is closer to the EAGLE definition, falls far below EAGLE's prediction.

The original test data obtained from open terrain were those that were initially suspected of incorporating ricochet fragments. In fact, for both the 30-degree and 60-degree munition elevation situations, there is a direct correlation between the lethal area computed using only the selected nonricocheting fragments and the EAGLE program for the nonricochet model. Furthermore, the computed lethal area using all of the collected fragments falls within the range of results derived from the predictive EAGLE computer program with the ricochet model. Without the ricochet model, the predictive lethality would have been far below the computed values.

In this last case, where environmental circumstances did not present a description problem for the basic predictive computer model, the ricochet model was proven to be an accurate description of the munition lethality.

The ricochet model is responsible for a slightly smaller and less divergent enhancement to the predictive lethal area than the enhancement contributed by the application of the ricochet criteria on the raw data. Thus, the ricochet model falls within a conservative description of ricochet effects. It is advantageous to have a conservative model until the phenomenon of ricochet can be more exactly defined.

SECTION IV

CONCLUSIONS

The in-depth analysis of selected munition tests from the DEP data clearly showed the presence of ricochet and provided a sufficient basis to establish a ricochet criterion from which a predictive ricochet model could be derived. This model incorporated in the EAGLE computer program provided the capability of producing comparative munition lethality data, which are presented in this report.

The ricochet model is an empirical model with capabilities and limitations similar to those implied in the DEP data. The effectiveness of this model can only be judged by direct comparison to observed test results. The application of certain assumptions may preclude the use of this model with other munitions. However, this study, as well as others, has shown the effect of ricochet on munition lethality.

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Hq USAF/SAMI	1
USAFTFWC/TE	1
USA Materiel Sys Anal Agcy/ AMXSY-GW	1
Hq USAF/RDQ	1
Hq USAF/OA	1
Hq USAF/SA	1
Hq USAF/RDP	1
AFSC/XRL	1
AFSC/XRP	1
AFSC/SDW	1
AFSC/DL	1
OASD/SA	1
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TAC/OAE	1
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